Soil Evaluator Course
Chapter 4

ESTIMATING HIGH GROUNDWATER ELEVATIONS

Reference:
Frimpter, M.H. 1981. Probable high ground-water levels in Massachusetts. USGS Open-File Report 80-1205.

http://ma.water.usgs.gov/water

SUMMARY

The U.S. Geological Survey (USGS), in collaboration with various Massachusetts state agencies, has been monitoring monthly water table levels in observation wells throughout the state since the 1930's. These long-term records allow prediction of seasonally high water tables in certain soil parent materials. The USGS method (also referred to as the "Frimpter Method") allows estimation of the seasonal high groundwater elevation at a proposed building lot based on current groundwater levels at the test site and the ratio of the present water level to the historic water level range in a network observation well located in the same geologic strata as the proposed construction site.

The method works well in unconsolidated sands and gravels typically associated with glacial out- wash and deltas. Due to the local character of precipitation patterns, the selected reference observation well and the test site need to be part of the same hydrogeologic environment. Actual water levels will not exceed estimates based on this method at a rate greater than 1 out of 10 years. The method works best in sandy strata of southeastern Massachusetts, including the southern portion of Cape Cod and the Islands.

Introduction

Title 5 defines the "high groundwater elevation in freshwater areas as "the elevation above which eight out of ten consecutive years the groundwater table does not rise." For soil evaluation purposes this elevation is commonly estimated using soil morphology, principally the presence of redoximorphic features. While this method works well under most natural conditions, it may lead to erroneous conclusions, particularly when the soil evaluator is inexperienced. Sandy soils, soils (red, black, gray) where the color masks the presence of redoximorphic features, or soils with E and Bhs horizons (Spodosols) are examples of situations where soil morphological features may be problematic. This tends to be only a small portion of all soils in Massachusetts.

Another approach to assess the high groundwater elevation may be to observe the soil during the so-called "wet season, typically February through April. The problem with that approach is that high water table levels vary seasonally and annually. These effects are illustrated in Fig. 1, where over a 3-year period the water table fluctuated between 21.8 feet below the soil surface in April 1970 and 28 feet in November 1971. Typically these fluctuations are dependent on the type of parent material. The maximum range of water levels (9 out of 10 years) between spring and fall is estimated to be 16 feet in tills, 9.2 feet in sands and gravels on terraces, and 4 feet in sands and gravels in valley bottoms (Frimpter, 1981).

The following page represents Seasonal water level fluctuations in the USGS Barnstable 230 observation well for the years 1969 through 1971 (source: Frimpter, 1981)

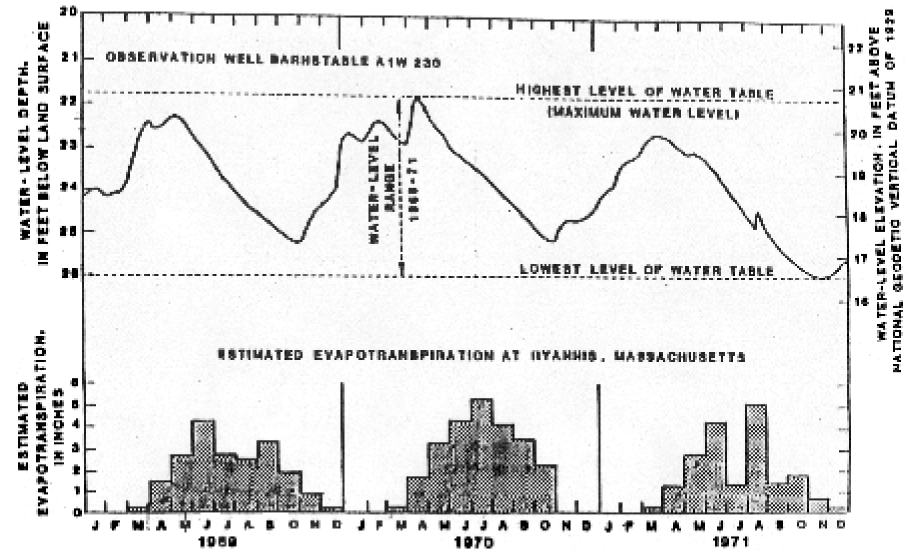

Fig. 1 Seasonal water level fluctuations in the USGS Barnstable 230 observation well for the years 1969 through 1971, (source: Primpter, 1981)

Estimating High Groundwater Elevation -The Wet Season Approach

Figure 1 shows the limitations of the wet season approach to determine seasonal high water tables. The highest groundwater elevation during this 3-year period was at 21.8 feet below the soil surface during a short time in April 1970. In 1996 the highest groundwater elevation was 22.3 feet, and in 1971 the maximum elevation was at 22.6 feet. Using the wet season approach each year would have resulted in a difference of about 10 inches from 1970 to 1971. If we had considered many more years of observations, this difference would have been even greater. Furthermore, neither the duration nor the groundwater elevation is constant throughout the wet season (Table 1). In 1969, the period with the highest average water table elevation ran from the end of March to the middle of May. An observation in early March would have indicated a groundwater elevation of about 24 feet, almost 2 feet below the level at the end of that month. In 1970 the period with the highest average groundwater elevation started in early January and lasted to about the middle of May. Observations during any other time would have resulted in a significant underestimation of the high groundwater elevation. The period with highest average water table elevations in 1971 went from the end of February to the end of May. Clearly, there is no distinct period of time of fixed duration in which groundwater elevations remain at a constant high level. For the Barnstable 230 USGS observation well, the period of time with relatively high water tables ranged from *11h* to *41h* months, while the high groundwater elevation estimates varied by as much as 0.6 feet (7 inches) during this 3-year period (Table 1).

Table 1. Wet season duration and average groundwater elevation for the Barnstable 230 observation well during the years 1969 through 1971.

	Season of Maximum Average groundwater Elevation	**Length of wet Season (months)**	**Average Groundwater Elevation Below Surface (feet)**
1969	March (end)- May (middle)	$1^{1/2}$	22.4
1970	January (begin) – May (middle)	$4_{1/2}$	22.6
1971	February (end) – May (end)	3	23.0

The USGS Observation Well Network

The duration of the wettest season and the level of the groundwater elevation depend on climatic conditions that are often not predictable on the short term. These include the amount of precipitation during and prior to the time of observation. It also depends on air temperatures that in turn affect plant growth and, consequently, the rate of evapotranspiration. Average precipitation in Massachusetts tends to be constant throughout the year, although patterns may vary from year to year.

The USGS Observation Well Network

Potential evapotranspiration rates increase with temperature and development of vegetation. It generally peaks in July and August and is about zero during the winter months (Fig. 1). During the growing season when evapotranspiration rates are high, the soil dries out and the water table drops reaching its lowest elevations in September and October, except during periods of heavy precipitation such as during hurricanes and other catastrophic storm events. The decrease in evapotranspiration and fairly constant precipitation rate causes water to be stored in the soil during late fall and early winter. Once the soil's water storage capacity is exceeded, water starts draining and replenishing the groundwater and water tables rise. Most groundwater recharge occurs during late winter and early spring from precipitation and melting snow and ice. Annual groundwater levels generally reach their maximum elevation during this time period (Frimpter, 1981).

Starting in-the 1930's the USGS, in collaboration with DEP and the Department of Public Works, established a network of observation wells throughout Massachusetts. Today there are about 100 observation wells monitored on a monthly basis. The wells were installed in representative parent materials and landforms throughout the state. Water table elevations are measured at the end of every month. The information is entered in a computer database that is Internet accessible through the following address: http://ma.water.usgs.gov/water.

The same website carries maps comparing the monthly readings with the historical record. This allows one to instantly assess whether an area has normal groundwater levels. Normal is defined as being within 25 percentiles of the median value. Water levels above the normal range fall in the upper 25% of all observations for that well during that month. Conversely, groundwater levels in the lowest 25% of all observations are considered below normal. Appendix II shows the groundwater map for data collected at the end of February 2000. Groundwater elevations on the Cape and in the southern portion of Berkshire County are below normal for this month. Sections of the North Shore and the triangle between Boston, Worcester, and Providence show water table levels above normal. Depending on the time of year and environmental conditions, this map may change considerably from month to month.

Estimating High Groundwater Elevation -Modified Wet Season Approach

As discussed earlier, estimating high groundwater elevations based on actual water table observations during the wet season may result in erroneous results, because of annual and seasonal hydrologic cycles. The use of the USGS observation network data may improve the accuracy of this procedure. For example, any test pit groundwater observations on Cape Cod during late February 2000, are highly suspect because the USGS *Current Conditions* map for that month shows that water tables during that time period were in the lowest 25% of all observations recorded for that month in that area. The Barnstable well was put in operation in 1957, thus the record spans a period of more than 40 years. If on the other hand the observations were conducted on the North Shore and the water table was observed say at a depth of 7 feet, we could conclude that this depth reflected close to the highest water table elevation because the historical record indicates that water table levels for that month were in the upper 25% of all observations ever taken in February in that region. Use of the USGS observation network thus allows comparisons of the observed water table level at a location with the historical record of observation wells in that area. This approach ensures that observations during the wet season indeed reflect the wettest conditions for that area.

Some Boards of Health have used correction factors based on the USGS observation network to correct for testing conditions when the water tables are not at maximum levels. This approach is based on the principle that if the water table in an observation well is below normal, this lower level is reflected at other sites within the town as well. Although that is true qualitatively, i.e. water tab1e elevations probably will be lower in other parts of the town, it does not mean that the levels are numerically the same at all locations. Just because the level in an observation well is say 1 foot below the mean for that month, not all sites within that town have water tables that are 1 foot below the mean for that location. Actual groundwater levels depend on parent material, local weather events, and hydrogeologic conditions. Only when a municipality has an extensive network of observation wells in a variety of geologic strata throughout the town, can differences in water table levels be properly assessed. Few towns are willing to invest time and resources in such an observation network, nor have the technical expertise available, to derive a realistic correction factor. A better approach to predict water table elevations at a certain location is to use the USGS estimation procedure that is explained in following sections.

In urban areas the hydrology may have been altered by sewering, installation of storm drains, paving, and drainage alterations, and the presence and depth of redoximorphic features may no longer reflect the current hydrology. Use of the USGS observation well network in combination with on- site water table measurements allow for a reasonably accurate determination of the new high groundwater elevation. If it is suspected that the redoximorphic features no longer represent the current hydrology, excavate a test hole during the time period when observation wells indicate maximum high groundwater levels for that area. The actual water level during that time period should be indicative of the new seasonal high water table. Installation of a well on site may facilitate the determination of the period with maximum high water tables. When using this estimation procedure, it is crucial that the water table in the observation well indeed reflects groundwater levels that are within the upper 10% of historic observations for that month. If the groundwater does not indicate maximum levels during field testing, the USGS method may provide a better estimate of the seasonal high groundwater elevation.

Estimating High Groundwater Elevation -USGS Method

Long-term monthly measurements of water levels in observation wells located throughout Massachusetts provide a record of maximum, mean, and lowest high water table levels on a monthly basis. These values differ by parent material and location, resulting from differences in physical soil properties, bedrock configuration, and climatic conditions throughout the state. The longer the period of measurement, the more refined the data set becomes. The USGS method is based on the principle that water tables in wells fluctuate in a similar fashion when installed in hydrologically connected aquifers. In unconfined sands and gravels these fluctuations may even be numerically identical. The numerical difference between water table levels in various observation wells may show a high degree of correlation, although numerically the fluctuations may not necessarily be the same. The correlation is strongest when observation wells are grouped by parent material.

Each year the USGS publishes summary statistics for each well in the network on the website http://ma.water.usgs.gov/water . The information for each observation well includes: year that monitoring started, elevation, maximum depth of the well, parent material, landform, maximum water level on record (OW_{max}), lowest water level ever recorded, and the recorded upper limit of the **annual** range for that well (OW_r). Note that the value for OW_r is generally less than the difference between OW_{max} and the lowest groundwater elevation value on record because the most extreme values are deleted from the tabulation.

The high groundwater elevation at a site can be estimated by correlation with the potential rise in a network observation well, if the climate and hydrogeologic conditions at the site and the well are similar. If the site has till parent material, the observation well selected for the estimation also should have till, occur on a similar landform, and should be as close to the site as possible. Similarly, in sandy soils the observation well used for the calculation should be in sandy and gravelly outwash or comparable deposits, in the same landscape position (i.e. either on terraces or in valleys), and as close by as possible. The high groundwater elevation can be estimated using the following equation (Frimpter, 1981):

$$S_h = S_c – [S_r \text{ X } (OW_c) – Ow_{max})/OW_r]$$

where

- $\mathbf{S_h}$ = estimate depth to the high groundwater elevation at the proposed building lot
- $\mathbf{S_c}$ = measured depth to the current groundwater elevation at the site
- $\mathbf{S_r}$ = expected range in water levels at the site. This value is based on the combined records of all observation wells for that parent material and landform.
- $\mathbf{OW_r}$ = historical upper limit of the annual range for the selected observation well
- $\mathbf{OW_c}$ = measured depth to the present groundwater elevation in the selected observation well
- $\mathbf{Ow_{max}}$ = maximum groundwater elevation on record for the selected observation well

The value for S_c is determined by measuring the actual groundwater elevation at the site for the proposed leaching facility. The measurement should be taken towards the end of the month, because the USGS observation wells are always read near the end of each month. Landform and type of parent material is typically recorded during the soil evaluation. If such an assessment has not been made as yet, the landform and associated parent material need to be determined at the location of the proposed leaching facility when S_c is measured.

The value for S_r is selected from probability graphs (see Figs. 2-4). These figures depict the maxi- mum range in groundwater elevations in a particular parent material given a certain probability. Frimpter (1981) developed charts for sands and gravels (typically outwash, kames, or deltas) either on terraces (Fig. 2) or on valley floors (Fig. 3) and for glacial till (Fig. 4). These charts show the maximum range that one can expect in a parent material given a certain probability level. For example, Fig. 2 indicates that in a coarse textured kame terrace the groundwater level range between: early spring and late summer will exceed 10 feet one out of 20 years (5% probability level). The maximum range of 9.4 feet will be exceeded once every 10 years (10% probability level). These values are obtained by selecting an appropriate probability level (for example 5%) and drawing a vertical line at the 5% level (see Fig. 2). At the point where the vertical and the curve intersect draw a horizontal line towards the left. The intersect with the Y-axis determines the level that may be exceeded at that probability level.

OW_r and OW_{max} are parameters based on long term measurements of groundwater levels in the USGS observation well network. At the end of each month the groundwater level in every well is measured and the data are entered into a database accessible through the USGS website http://ma.water.usgs.gov/water. The data are tabulated and compared to previously collected groundwater levels. OW_{max} represents the highest groundwater elevation that reasonably can be expected in that particular reference well. OW_r represents the maximum range in values that can be expected for that observation well. As noted earlier, the value for OW_r is generally less than the difference between OW_{max} and the lowest groundwater elevation value on record because the most extreme values are deleted from the tabulation. Values for OW_{max} and OW_r can be obtained from the USGS website. If the observation well was installed many years ago, the OW_{max} and OW_r values will not change much from one year to another. If the well installation was more recent it is imperative that the values of these parameters are obtained from the most current data on the USGS website.

The value of OW_c reflects the groundwater elevation in the observation well during the same month that the groundwater level at the proposed building lot is determined. Select the appropriate month from the USGS web site. Values for OW_c are the monthly well readings that are available in the monthly data table.

groundwater elevation for this particular month is exceptionally high or low. If these symbols are lacking, the OW_c falls in the normal range (25 to 75 percentile).

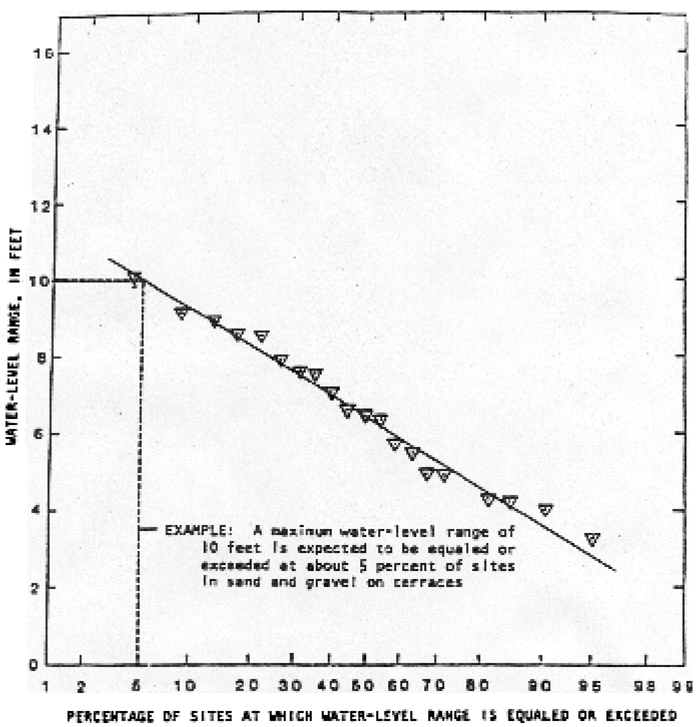

Fig. 2. Probability of water level range in sands and gravels on terraces.
(source: Primpter, 1981)

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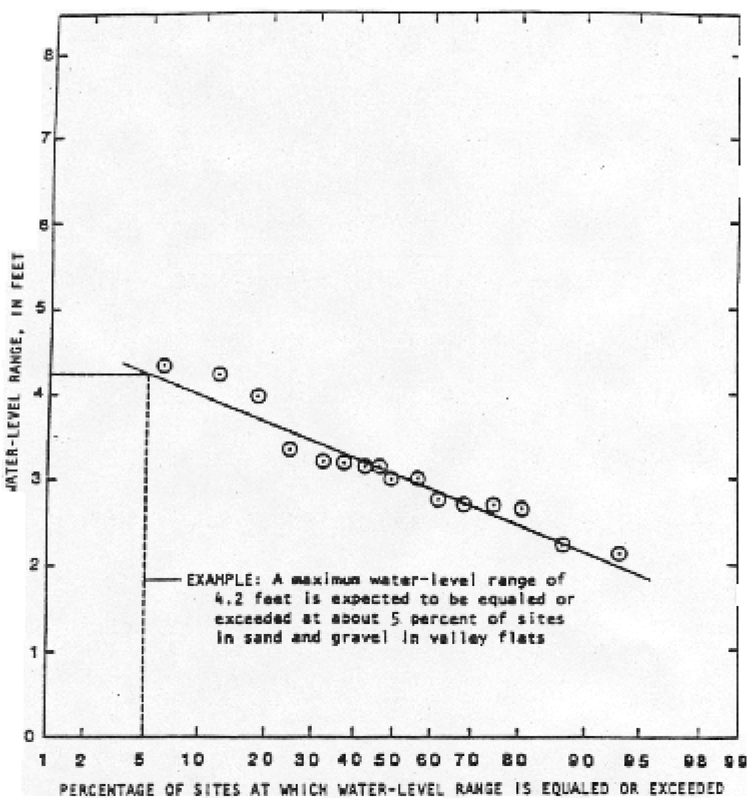

Fig. 3. Probability of water level range in sands and gravels in valley flats. (source: Frimpter, 1981)

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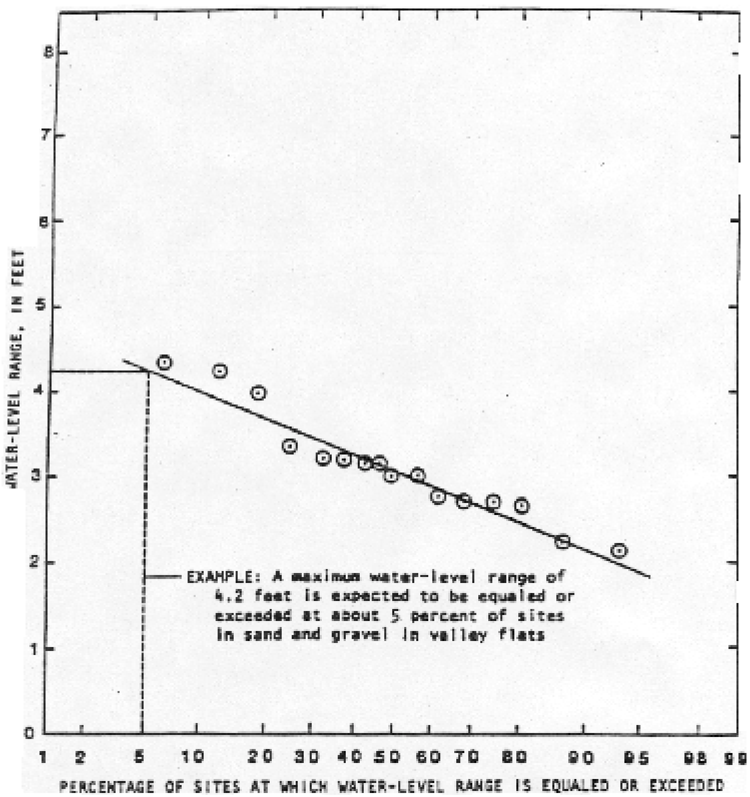

Fig. 3. Probability of water level range in sands and gravels in valley flats.
(source: Frimpter, 1981)

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Sample Calculation to Estimate High Groundwater Elevation Using the USGS Method

The following provides an example demonstrating how one may calculate the high groundwater elevation at a site in Lakeville located in southeastern Massachusetts. An earlier soil evaluation showed that the site was located on stratified sandy deposits on a kame terrace. The groundwater level at the proposed building site is 8.0 feet below the soil surface. The groundwater level was measured on February 27, 2000.

Using equation (1) on page 5 we can calculate the high groundwater elevation at the proposed leaching facility. Following is an explanation of the origin of the various values used in the calculation. The value for S is determined at the proposed leaching facility site by measuring the groundwater elevation. As stated in the previous paragraph this level was determined to be 8.0 feet.

The value for S is selected from probability graphs (see Figs. 2-4). The parent material for the proposed site is sandy sediments located on a kame terrace. Figure 2 pertains to sand and gravel deposits on terraces and should be used to estimate S. Lets assume that we want to predict the high groundwater elevation based on a probability that this value will not be exceeded more than once in 20 year (5% probability). Draw a vertical line at the 5% probability level and determine the intersect with the probability curve. In Figure 2, this is illustrated by the dashed line. At the intersect draw a line to the left parallel with the X-axis. The intersect with the Y-axis gives the value for S_r for the 5% probability level. In this example S_r equals 10.0 feet.

The next step to calculate the estimated high groundwater elevation is to select an appropriate USGS observation well. The #14 well in Lakeville is nearby and is located in the same aquifer as the proposed construction site and therefore can be used as a reference well. For the purposes of this exercise we will assume that the values for OW_{max} and OW_r are 9.28 and 10.45 feet, respectively. Also, OW will have a value of 16.1 feet in February. (Value for OW is obtained from the USGS website for the same month that S was measured http://ma.water.usgs.gov/water.)

All variables now have been determined and can be substituted in equation (1) as **follows:**

$$Sh = S_c - [S_r \text{ X } (OW_c - OW_{max})/OW_r]$$

$$Sh = 8.0 - [10.0 \text{ X } (16.1 - 9.28)/10.45] = 1.5 \text{ feet}$$

Note: always subtract the numbers in parentheses first before multiplying and dividing.

The predicted high groundwater level at the proposed site is 1.5 feet below the soil surface. This indicates that there is not enough separation between the high groundwater level and the bottom of the proposed leaching facility. Use of clean fill (see Title 5 for fill specifications) can increase this distance to the proper level. If the underlying soil has a percolation rate faster than 2 minutes per inch the separation distance should be 5 feet. If the perc rate is slower than 2 minutes per inch, the separation between the high groundwater elevation and the bottom of the leaching facility should be a minimum of 4 feet. High water tables do not automatically exclude a site for on-site sewage treatment and disposal systems. It does require a special design approach that generally raises installation costs.